



# Impacts of coal-fired power plants for energy generation on environment and future implications of energy policy for Turkey

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## Abstract

Turkish government aimed to increase the installed capacities of coal-fired power plants (CFPPs) according to several policies and strategic plans published in recent years. Energy production from CFPPs and subsidizing the coal sector were selected for reducing the import dependency as a cheaper option. CFPPs with gaseous emissions as well as fly ash and fine dust, along with ash storage, coal storage, and coal mining operations and water use for cooling of the plants, affect the environmental quality. Hence, the health of inhabitants of the environment is affected. CFPPs to be built, according to strategic plans, will emit a significant amount of greenhouse gases (GHGs) and would severely undermine the targets for a 1.5 °C or 2 °C warmer world. Subsidies to the coal sector, along with exemptions from environmental regulations, combined with slower growth of energy production from renewable energy sources (RES), may lead to a path dependence on coal, while the rest of the world increases their energy production from RES. This study demonstrates the concrete examples of pollution caused by CFPPs in Turkey, along with health effects with the addition of policy context toward utilization of CFPPs, to point out the risks these plants constitute both for the environment and economy. Increasing the share of RES in the energy mixture is particularly important for Turkey due to being in a geographical region that is highly vulnerable to climate change effects. This study also briefly discusses how the increase of RES and de-carbonization in Turkey could be conducted in the short- and long-term, upon the literature provided.

**Keywords** Coal-fired power plants · GHG emissions · Air pollution · Environmental effects · Energy policy · Renewable energy

## Introduction

The fast-growing population, increased urbanization, and industrialization led to significant energy demand in Turkey. The trend of increasing energy demand, with a nearly 5% yearly increase in 2010, is likely to continue in the following years (Erat et al. 2021; Telli et al. 2021). Turkey has limited fossil fuel resources, and imports of fossil fuels are essential for energy production (Udemba 2021). Throughout the OECD (Organisation for Economic Co-operation and Development) countries, Turkey has been the most energy-import-dependent country in the last decade (Ağbulut et al. 2021).

In 2018, natural gas imports were 99.6% of the natural gas demand and oil imports were 93.9% of the oil demand, where coal import dependency was at 61.9% (Karagöz 2019). Therefore, the share of renewables along with indigenous fuel sources should be increased to meet the energy demand without relying on imports. In order to secure the national energy demand, a 25% increase in indigenous sources in energy production was achieved in 2019, where most of this nationalization occurred from the increase (34.6 BkWh of 37.3 BkWh) in renewable energy sources (RES) and the rest occurred from the use of indigenous coal reserves (TKİ (Türkiye Kömür İşletmeleri Kurumu-Turkish Coal Enterprises) 2020).

Total energy production of Turkey in 2019 was reported as 304.24 billion kWh, of which 113.12 BkWh (37.2%) was supplied from coal-fired power plants, 90.24 BkWh (29.7%) from hydroelectric powerplants, 56.32 BkWh (18.5%) from natural gas-fired powerplants, 40.36 BkWh (13.3%) from other renewable energy sources (wind, solar,

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and geothermal), and 4.20 BkWh (1.4%) from biomass and fuel oil (TÜİK (Türkiye İstatistik Kurumu-Turkish Statistical Institute), 2020). Renewable energy sources increased their share in total energy production in Turkey; however, they are still limited in capacities. Coal constituted 37.2% of the total energy production according to Turkish Coal Enterprises (TÜİK (Türkiye İstatistik Kurumu-Turkish Statistical Institute), 2020) and 37.3% according to Climate Transparency Report (Climate Transparency 2020), respectively (Fig. 1).

In 2020, 305.46 billion kWh of which 106.38 BkWh (34.8%) was supplied from coal-fired power plants, 78.12 BkWh (25.6%) from hydroelectric power plants, 69.36 BkWh (22.7%) from natural gas-fired power plants, 45.88 BkWh (15%) from other renewable energy sources (wind, solar, and geothermal), and 5.72 BkWh (1.9%) from biomass and fuel oil in 2020 (TKİ 2021, Avcı 2012). A decrease in coal in energy production was observed along with hydro power; however, this decrease was covered with natural gas, and the increase in renewable energy sources remained limited. Consequently, coal still made up more than one-third of the electricity production in Turkey.

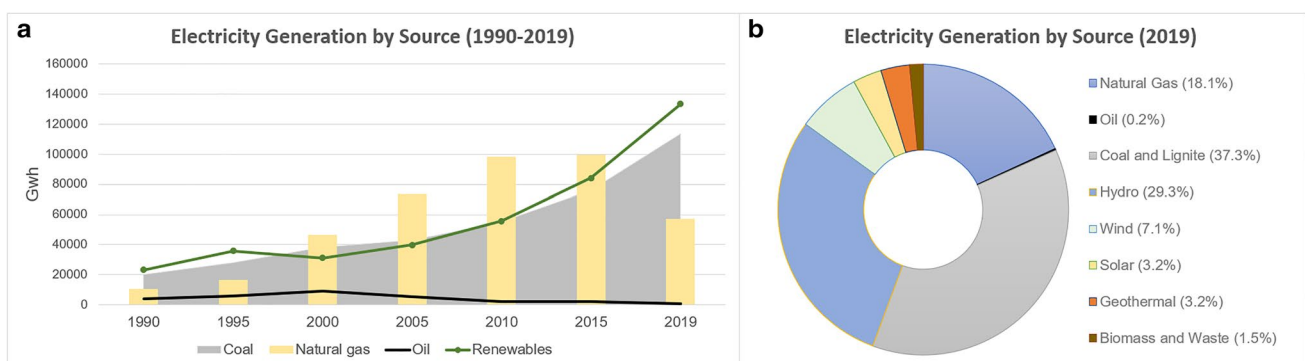
The objectives of reducing energy dependency by 2023 include increasing the renewables share in energy production (up to 30%); however, the same plan also includes a two-fold increase in coal-fired power plants (CFPPs) from 2019 to 2023 (Melikoglu 2017; TMMOB 2020b). Production from imported coal, fuel oil, and natural gas is therefore caused by a budget deficit, causing an increase in energy prices and negatively affecting the security of energy supplies. Moreover, it adversely affects the environment (Ediger et al. 2018). Energy generation from fossil fuels causes more greenhouse gas (GHG) emissions than renewables, and production from coal (especially from lignite) is the most polluting (Şahin et al. 2016; Atilgan and Azapagic 2015).

Coal demand and production dropped worldwide when restrictions were imposed due to the Covid-19 pandemic, and the same trend was also observed in Turkey (Mishra

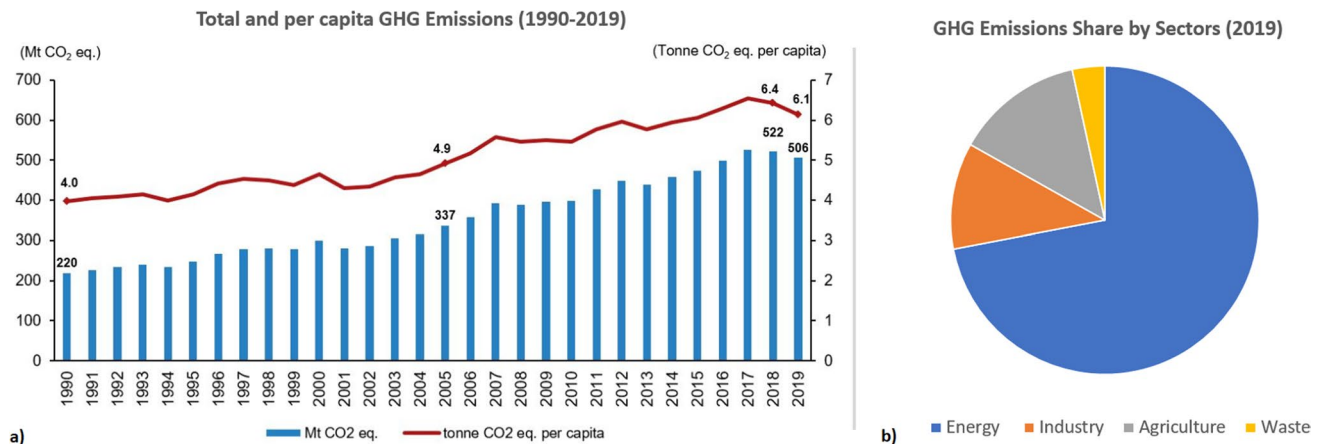
et al. 2021). A slight decrease was observed in some major air pollutants that are being monitored in 2019. Decrease in PM (particulate matter), SO<sub>2</sub>, and NO<sub>2</sub> emissions, along with the increase in O<sub>3</sub> concentrations, were reported in Turkey, where the decreases varied between the regions (Sari and Esen 2021; Dursun et al. 2021). GHG emissions decreased by 3.1%, according to the Turkish Statistical Institution in 2019, compared to 2018, though the upwards trend continued from 1990 to 2019 (TÜİK 2020). The energy was the main contributor to GHG emissions with a share of 72% in 2019 (Fig. 2), where this contribution was reported to be 70% in 2012 (Şahin et al. 2016; TÜİK 2020). These figures included the energy used in transportation and industry, where energy industries constituted 37% of GHGs where the world average was 41% (TÜİK 2020; Saint Akadiri et al. 2020).

Turkey is located in one of the most climate-sensitive regions, and projections predict that Turkey will adversely be affected by temperature increase caused by global warming (Şahin et al. 2016; Climate Transparency 2020). Extreme weather events such as heavy precipitation, heatwaves, droughts, cyclones and resulting floods, wildfires, crop losses, and extreme storms affect many regions throughout the world and articulated with anthropogenic activities that result in global temperature increase as stated in the IPCC (Intergovernmental Panel on Climate Change) 6th Assessment Report (IPCC 2021) and Turkey, along with Mediterranean countries, faced these difficulties in the recent past. An increase in the energy sector's share in GHG emissions is a major concern with respect to the environment and global climate change, especially considering the planned increase of CFPPs.

Therefore, the primary aim of this study is to assess and summarize the coal's share on energy production, the origins of the coal that is utilized, and the future aims of coal utilization for energy production in Turkey. Subsequently, literature on the environmental effects of CFPPs in Turkey will



**Fig. 1** Power generation of Turkey based on energy sources from 1990 to 2019 (a) and distribution of energy sources in power generation in 2019 (b) (Climate Transparency 2020, IEA 2020)



**Fig. 2** GHG emissions in Turkey in 1990–2019 period (a) and share of sectors in GHG emissions in 2019 (b) (TÜİK 2020)

be summarized in order to demonstrate their effects on the environment and to point to the hazards with coal expansion. Coal-fired power plants and their relationship with GHG emissions will also be discussed. Future plans and policies of interest regarding the future energy mixture will be discussed briefly in order to evaluate the potential changes for energy mixture in Turkey for a better and more sustainable environmental quality.

### Energy policies, coal outlook, and CFPPs' role in energy generation

According to BP (British Petroleum) Statistical Review of World Energy 2020, Turkey has 550 million tons of bituminous and anthracite coal reserve and 10,975 million tons of lignite and sub-bituminous coal reserve with a total of 11,525 million tons, corresponding to 1.1% of the world's reserves (BP 2020). However, according to MTA (Turkish General Directorate of Mineral Research and Exploration), there are more than 19,000 million tons of lignite reserves in Turkey and the reserves account for 2.1% of the world's coal reserves (MTA 2019; TMMOB 2020a). One-fourth of Turkish lignite coal reserves are located in the Afşin-Elbistan area (MTA 2019; TMMOB 2020a). Turkish hard coal reserves are also estimated as 1517 million tons, where 60% of the reserves are located in Zonguldak (TTK 2020). Turkish lignite coals have high ash percents and total sulfur, where coals extracted from Soma, Karapınar, and Şahinali are also reported to contain high concentrations of As, Cd, Ni, Hg, Pb, Sb, Se, Th, and U (Karadirek et al. 2019).

The total share of coal in energy production was 37.2% with 113.2 BkWh in 2019 and 34.8% with 106.38 BkWh, as mentioned previously. In 2019, the share of the imported coal was 60.38 BkWh in CFPPs, where plants utilized national reserves remained behind with 52.74 BkWh. In

2020, the share of imported and indigenous coals were 62.17 BkWh and 43.91 BkWh, respectively. Production of hard coal increased in 2019; however, it was not sufficient to cover the energy demand of Turkey and needs to be subsidized. In order to sustain the power plants working with hard coal, 37.7 million tons of hard coal were imported in 2019, according to EURACOAL (European Association for Coal and Lignite), and Turkey was the second-largest importer after Germany (EURACOAL 2020).

According to EMRA (Energy Market Regulatory Authority), in 2020, there were 28 coal-fired units using indigenous coal and 30 units using subsidized coal that had production permits and 4 units that are pre-permitted in operation (EMRA 2021). According to End Coal January 2021 data, Turkey has 32 operational CFPPs consisting of 70 units, 3 plants with 5 units are still under construction. There are also 10 units that are permitted and 2 units pre-permitted (End Coal 2021).

In the Ministry of Energy and Natural Resources (MENR) 2019–2023 Strategic Plan, the nationalization of power sources is projected to increase from 59 to 65% (MENR 2020). The strategic plan aims to increase the share of renewables in the energy mixture as well as the National Renewable Energy Action Plan (MENR 2014a) and the 2015–2019 Strategic Plan (MENR 2014b). Solar power and hydro power are the strongest options for energy generation, due to their potentials in the country, along with other RES, according to the plan. Targets for RES utilization and total distribution of energy sources in 2023 are listed in Table 1 along with actual installed capacities by the end of 2021 (TEİAŞ (Türkiye Elektrik İletim A.Ş.-Turkey Electricity Transmission Company) 2021), for comparison, in order to track the actualization of targets that were set by the authorities.

The aforementioned documents also mention further investments in nuclear power and the trial of the Akkuyu

**Table 1** Targets for renewable energy sources (RES) and overall energy output in 2023, gathered from several official documents and the most current situation

Installed capacities of power plants by energy sources (MW)								
Document/reference point	Hydraulic	Wind	Geothermal	Biomass	Solar	Total RES	Fossil fuels	Total
Turkish National Renewable Action Plan (2013–2023)	34,000	20,000	1000	1000	5000	61,000	64,000	125,000
Ministry of Energy and Natural Resources 2015–2019 Strategic Plan	32,000	10,000	700	700	3000	46,400	N.A	N.A
Ministry of Energy and Natural Resources 2019–2023 Strategic Plan	32,037	11,883	2884		10,000	28,000	N.A	N.A
Situation by the end of 2021	31,492	10,607	1676	1644	7815	53,236	46,193	99,819

Nuclear Power Plant's (NPP) first unit; however, the impact of the plant was not considered in overall distributions. To briefly summarize, two nuclear power plants that are under construction are expected to produce 80 billion kWh of electricity, which is equal to the energy produced from 16 billion m<sup>3</sup> of natural gas (Es and Hamzacebi 2021). The share of electricity production of nuclear power plants is expected to be 15% in 2023 (Ağbulut et al. 2021). The plans do not mention the risks related to an NPP accident that might occur (Akyuz 2021).

National Energy Efficiency Plan was announced in 2018, and a reduction in primary energy consumption by 14% was aimed with the plan (Önay et al. 2021). The 2019–2023 Strategic Plan supports energy conservation measures that have to be undertaken in order to reduce the energy demand. Utilization of less power-consuming lighting appliances, preparation of a potential regional district heating, and cooling map are listed as measures along with increasing the efficiency in energy production (MENR 2020; Akyuz 2021).

Apart from the increase in RES and acceleration of nuclear power utilization and energy conservation measures, in the 2019–2023 Strategic Plan, an increase in fossil fuels for energy generation is also projected. The plan states that increase of natural gas utilization in public and private sectors to increase by 2- and sevenfold, respectively. Reduction of the dependency on oil and gas imports, via expansion and acceleration of oil and natural gas explorations, especially in the sea, is also given as priority objectives. In addition, the National Renewable Energy Action Plan also aims to increase RES in energy mixture; however, CFPPs are also planned to increase. The plan states that installed capacities of CFPPs that utilize indigenous coal is going to increase by 44% in 2023, compared to 2019 (from 10,204 to 14,664 MW) (TMMOB 2020b). In April 2017, The National Energy and Mining Policy was announced by the MENR. The plan is aimed to increase CFPP energy generation to 30 GW from 17.3 GW by giving extended purchase guarantees, capacity mechanisms, and advantageous feed-in tariffs to CFPPs utilizing clean coal technologies (EURACOAL; Udemba 2021).

According to a report published by Şahin et al. (2016), in 2016, 70 new CFPPs are planned to be constructed, where some are licensed, pre-licensed, at EIA (Environmental Impact Assessment) stage or announced in Turkey due to 2030. Some of these plants were planned with extremely large capacities such as Afşin-Elbistan C-D-E units with 6500 MW total installed capacity and Konya-Karapınar CFPP with 5250 MW total installed capacity. The largest existing CFPPs have installed capacities of 1000–1500 MW of installed capacity, and the rest are around 400–600 MW. The plants to be constructed correspond to 66.5 GW, and existing plants in 2016 are only one-fourth of the planned CFPPs (Şahin et al. 2016). Moreover, they constitute a higher installed capacity than all of the fossil fuel plants in operation (as of the end of 2021). As of 2017, Tagliapietra and Zachmann (2017) reported that Turkey had the world's third-largest CFPP development plan.

After MENR announced the year 2012 as “the year of coal,” the Turkish coal sector is subsidized in order to increase the indigenous resource utilization, where in 2013, it received 730 million dollars of research and development subsidies (Şahin et al. 2016). The incentives provided were exemption from customs duty and vat, tax reduction, investment allocation, interest subsidies, support of income tax withholding, and support for the employer share of insurance premiums in several regions (Yıldızhan 2017). These subsidies were generally in favor of hard coal, which is mainly imported where there was an inequality between hard coal and the lignite, and this also resulted in the continuity of imports (Acar et al. 2018; Şahin et al. 2016). The utilization of hard coal in CFPPs is therefore higher than indigenous coal in the CFPPs (TKİ 2020, TKİ 2021). In addition, with the support given to coal-based energy generation overall, the coal exploration and extraction activities also intensified (Tagliapietra and Zachmann 2017).

Exemptions from environmental regulations are also provided for existing CFPPs, and EIA procedures that are permissive also increase the environmental consequences of the CFPPs (Acar and Yeldan 2016). In the development plans, coal mining areas are also designated as “priority areas”

and new plant projects are also continued to be subsidized (Acar and Yeldan 2016). The financial guarantees on energy generation from fossil fuels and prioritization of their exploration and exploitation exerts more pressure on the energy production budget (Karasoy 2019). Constructed and pre-permitted CFPPs that receive incentives and subsidies, new coal fields that are being permitted, along with new and existing CFPPs which will have 40–50 years of average economic lives, prove that, despite the increase in RES, coal-based energy production is going to survive even after 2023 (Şahin et al. 2016; TMMOB 2020b; Karagöz 2019).

## Environmental effects of coal-fired power plants

CFPPs, like other thermal plants, generate large quantities of solid wastes and flue gas emissions and, therefore, have several environmental effects. Flue gases, bottom ash, and fly ash formed during fuel combustion are examples of pollution occurring from the combustion process. Land use of the power plant, coal mining and transport, and feeding of the coal to the combustion chambers can also cause pollution. The cooling water is another pollution source to the surrounding water systems. GHG emissions are also a major concern and one of the most significant disadvantages of CFPPs. Environmental effects of energy production from coal, with respect to types of emissions, in Turkey, are evaluated in this section.

### Flue gas and fly ash emitted

Despite the removal equipment, such as electrostatic filters and flue gas desulfurization units, some of the fly ash from stacks are still discharged to the receiving environment (Kursun and Terzi 2016). The flue gases ( $\text{SO}_x$ ,  $\text{NO}_x$ ,  $\text{CO}_2$ , CO, ozone, HCl, and PM) are important sources of air pollution in plant's impact area (TTB 2014; Hepbasli 2004; Baştabak et al. 2021). Around 2/3 of the  $\text{SO}_x$  and 1/3 of  $\text{NO}_x$  emissions of Turkey have been reported to occur from fuel combustion and power generation sectors (IEA Clean Coal Centre 2014). 46% of the  $\text{NO}_x$  emissions in Turkey resulted from of energy use and production, where 62% of  $\text{SO}_2$  emissions resulted from energy production, reaching up to 85.6% when combined with energy use (Kaygusuz 2021).  $\text{SO}_x$  emissions are important for Turkish CFPPs as the Turkish lignite contains a considerable amount of sulfur in variable ratios (0.21–10.66%) throughout the country with an average of 2–3% sulfur (IEA Clean Coal Centre 2014; Atılgan Türkmen et al. 2021).

More than half of the  $\text{SO}_2$  emissions in Çanakkale are estimated to occur from CFPPs (Akyuz and Kaynak 2019; Mentese et al. 2020). Domestic use of coal is also another

contributing factor due to the use of low-quality lignite for heating (Mentese et al. 2020). Air pollutants in Çanakkale were above the WHO (World Health Organization) limit values during the 2014–2018 period (Arslan et al. 2022). PM 10 limit was exceeded in 59–69% of the duration investigated, and the  $\text{SO}_2$  limit was exceeded 46–82% of the duration. PM 10 and  $\text{SO}_2$  were found to be correlated with asthma in children, where PM 10 and  $\text{SO}_2$  correlated with chronic obstructive pulmonary disease in adults and the elderly. In a modeling study, Seyitömer CFPP was estimated to be the major source of  $\text{SO}_2$  and  $\text{NO}_x$  emissions in Kütahya, where 94% and 85% of the total emissions of these pollutants are estimated to have resulted from the plant (Tuygun et al. 2017). PM 10 emissions in Kütahya were significantly higher compared to other cities in the Aegean region due to CFPPs, according to Bilginer et al. (2021), and  $\text{SO}_2$  values were higher than the legal limit values in the whole region. The coal used in heating also causes a significant PM 10 emission. Lignite mines supplying two major power plants were also estimated to make up 86% of total PM 10 emissions. Moreover, Kahramanmaraş, Kütahya, and Manisa had the highest PM 10 values due to the presence of several CFPPs in the region (Cekim 2020). Soma, Manisa, station had the highest concentration of  $\text{SO}_2$  which was 220 times of the limit value, where the highest concentration of CO was observed in Çatalağzı, Zonguldak, in a study evaluating the air quality of Turkey. The study used data from air quality monitoring stations recorded in 2018 and 2019 (Zeydan and Pekkaya 2021). Several CFPPs are operating in these cities, where in Soma, there are also several mines in operation (Gündoğdu 2020).  $\text{SO}_2$  and PM 10 emissions were the major air pollutants of concern in a modeling study conducted using the data from air quality monitoring stations (July–September 2019) (Gündoğdu 2020). PM and ash in the flue gas were emitted toward the sea from Çatalağzı CFPP, and these particles created pollution through floating flocs accumulated on the sea surface (Avcı 2005).

According to a study conducted with 2019 data, comparing emissions from CFPPs in European Union (EU), United Kingdom (UK), Western Balkan Countries, Ukraine, and Turkey where  $\text{SO}_2$ ,  $\text{NO}_x$ , and PM 10 were reported; Turkey ranked first and second in  $\text{NO}_x$  and  $\text{SO}_2$ , respectively, by a narrow margin, followed by Germany and following Ukraine. Ukraine was reported to be on the top polluter spot in PM 10 emissions, followed by Turkey with emissions with sixfold emissions; however, Turkey emitted nearly threefold emissions than following Serbia. In 2018, 33% of  $\text{SO}_2$  emissions from the energy sector resulted from Turkey, throughout OECD countries, because of a lack of flue gas desulphurization (FGD) units (Ember 2021). The benefits of electrostatic precipitators (ESP) and FGD systems are demonstrated in several studies; therefore, the lack of these units aggravates the adverse effects of CFPPs on the

environment (Vardar and Yumurtaci 2010; Büke and Köne 2011). Flue gases contain SO<sub>x</sub>, and a significant part is SO<sub>2</sub>, where depending on the temperature and excess air, little amount of SO<sub>3</sub> (1–10%) (Eksi and Karaosmanoglu 2018). In wet FGD systems, 0.25–1.25 of SO<sub>2</sub> can still be converted to SO<sub>3</sub> with the flue gas moisture and form sulfuric acid aerosol with lowered temperatures (Yang et al. 2018), eventually causing acid rains.

HF, non-methane volatile organic compounds (NMVOCs), and ozone are also emitted in relatively smaller amounts with fly ash and flue gases (TTB, 2014; Küçükaçıl Artun et al. 2017). Samples from the Göynük CFPP impact area and coal operation area contained PM 10 and deposited dust (Ercan et al. 2020). High concentrations of PAHs and PCBs were also observed in the impact area of the CFPPs and urban areas. Major contributors estimated to be CFPPs and coal used in heating (Ari et al. 2020; Dumanoglu et al. 2017) in Kütahya, where high VOC and SO<sub>2</sub> levels were also observed in regions closer to the CFPP (Küçükaçıl Artun et al. 2017). VOCs are both toxic and carcinogenic (Küçükaçıl Artun et al. 2017). In the presence of high temperatures and daylight, CO<sub>2</sub>, CH<sub>4</sub>, and NMVOCs, combined with NO<sub>x</sub>, favor tropospheric ozone production, and this occurs to be a dynamic equilibrium of O<sub>3</sub> and NO<sub>x</sub> (Melkonyan and Kuttler 2012). Tropospheric ozone is also a highly reactive gas associated with an adverse effect on both humans as well as biota (Li et al. 2015; Nuvolone et al. 2018).

Heavy metals that are present in the fly ash can also spread via the winds, and they can reach surface waters and groundwaters via precipitation events. Fly ash and bound heavy metals released into the atmosphere can enrich the toxicity of the SO<sub>x</sub> and NO<sub>x</sub> and catalyze the acid rain formation (Ertürk et al. 2006). Karaca et al. (2009) found out that soil samples along the wind direction contained higher concentrations of heavy metals compared to the opposite direction from Çayırhan CFPP in Ankara. Soil samples from pine and olive forests in Muğla (Tuna et al. 2005) and soils in Sivas (Turhan et al. 2020), Kahramanmaraş (Çayır et al. 2012), Kütahya (Özkul 2016), and Muğla (Baba et al. 2003) reported to have contained heavy metals in moderately high to severe amounts. Radioactive elements that are incorporated in coal in natural environments are another source of pollution. Radioactive elements (such as U and Th) were present within the fly ash and the flue gas produced during combustion in Zonguldak (Aytekin and Baldık 2008). Radionuclides with differing intensities observed in various regions where CFPPs operated such as Kangal (Turhan 2020), Afşin-Elbistan (Cevik et al. 2008; Çayır et al. 2012), Yatağan (Baba 2002; Kursun et al. 2016), and Soma (Kursun and Terzi 2016). On the contrary, Gören et al. (2017) reported that despite the fly ash being more enriched with radionuclides, no significant radiation was observed in the

Kangal CFPP vicinity. The authors stated that emission control systems that were utilized were effective in the prevention of the spreading of radionuclides. No significant radiation could be observed, despite several radionuclides that are slightly above threshold limits. The enrichment of radionuclides was reported to occur along with the emission control systems in Ozden et al. (2018). The authors also reported that enrichment of these volatile radionuclides and some trace metals are inversely correlated with particle sizes. Uğur et al. (2009) reported excess atmospheric fallout of <sup>210</sup>Pb in wind direction; however, they also reported that the study site was not affected by the pollution due to the presence of high stacks and presence of high trees in that direction. Soil radioactive nuclide and heavy metal contamination in Kütahya, Manisa, and Muğla, from the literature reviewed, is reported to be due to CFPPs in Baştıbak et al. (2021).

SO<sub>x</sub> and NO<sub>x</sub> are deposited in the atmosphere, and they react with water droplets, forming sulfuric and nitric acids causing acid rains with precipitation (TMMOB 2017). 50 kg (SO<sub>2</sub> eq.) of acid precipitation was estimated in a 90 km<sup>2</sup> area around the thermal plants (CAN Europe 2019). Rainwater acidity was moderately affected by flue gas emissions in Yatağan (Demirak 2007). SO<sub>x</sub> emissions from flue gas can accumulate in the surrounding environment. High amounts of sulfur accumulation in plants and soil were observed in Kütahya, where the soil was much more acidic in the region of CFPP (Cicek and Koparal 2006). Annual ring widths of pine trees in Yatağan, Muğla, significantly decreased after the power plant began to operate, and the volume of the trees has also decreased. The concentration of sulfur in needles of the pine trees (mg sulfur/kg) was also reported to be 2- to threefold of unpolluted areas in Yatağan. Trees on 2271 ha of forest land were cut down due to a drought caused by air pollution, where the Yatağan power plant was first operated (Tolunay 2003). Sulfur and heavy metal concentrations were detected in tissues of tree leaves in Kütahya (Çiçek and Koparal 2004). Staining due to SO<sub>2</sub> was observed in trees and fruits, where morphological deformations such as color changes and decortifications as well as growth inhibition (by 30–40%) were observed in plants and trees (Cicek and Koparal 2006). SO<sub>x</sub> generally negatively affects the vegetation growth rate and thereby causing a decrease in productivity and yields. Even Çatalağzı CFPP, which utilizes hard coal, was linked with negative growth effect on trees (Avcı 2005). Particles that are < 10 μm were found to affect the stomata of the olive tree leaves. Fine dust and SO<sub>2</sub> emissions caused the olive flowers' female organs to dry and decrease the olive yield (Kantarıcı 2018). Agriculture, therefore, is also affected by CFPPs (CAN Europe 2019).

Fluorosis that affects kidney functions was detected in the sheep due to fluorine compounds in the flue gas and fly ash (CAN Europe, 2019). A significant rate of cytogenetic

damage was observed in workers of Afşin-Elbistan CFPP. Patients receiving treatment for respiratory diseases in Yatağan are twice more than the ones in Muğla, where three times more patients are observed for bronchitis, emphysema, and asthma, which they can be enhanced by CFPP emissions (TTB 2014). According to an HEAL report, Çerkezköy CFPP that is being planned will cause 5640 early deaths in its 40 years of lifetime (Ekologos 2018). The emissions also disperse to distant locations, as CFPPs emissions from Muğla are reported to reach Aydın (North), Rhodes and Egypt (South), and Palestine and Israel (East) with winds and atmospheric events (Myllyvirta 2018). Du et al. (2020), in a modeling study, compared the transboundary emissions of the world using CFPP emission data and dispersion models. Turkey was the third-largest transboundary emitter, where China and India were the first two with two- to several-fold transboundary emissions, respectively. Iraq and Egypt were the two countries Turkey exchanges transboundary emissions the most.

Carrot and sesame samples were also reported to have been contaminated with Zn, Pb, Cd, and Cu (Haktanır et al. 2010). Demirak et al. (2006) stated that the heavy metals (Cd, Cr, Pb, Zn, and Cu) which were found in the tissues of carps may have resulted from Yatağan CFPP. In Elbistan plain, around the Afşin-Elbistan CFPP area, Akarsu et al. (2022) investigated rams for changes in heavy metal levels in their blood serum and testicular tissues and to evaluate their effect on reproductivity. CFPP was found to be an important factor for the heavy metal pollution in the soil in its vicinity, and rams were thus negatively affected. Blood serum levels were higher in the rams closer to the CFPP, and structural and functional disorders were observed with the reproductive systems of rams. Disorders in hormonal systems were also observed. Elevated heavy metal concentrations were reported to be related to CFPPs, coal mining, and other mining operations in Çanakkale, along with geographical characteristics (Mentese et al. 2021). Although heavy metal (especially As) concentrations were reported to be significantly high in the honeys in Muğla, around Yatağan CFPP (Kantarci 2018), there were several studies contradicting this statement in earlier studies, which were held in the vicinity (Silici et al. 2013). Tissues of wild sparrows were also reported to have contained large amounts of heavy metals, indicating that wildlife was also affected by the pollution (CAN Europe 2019). In Yumurtalık, Adana, the highest concentrations of Cu, Ag, and Cr in sampled mussels were recorded (Belivermiş et al. 2016b). Authors speculated that this could result from two CFPPs and two harbors in the area. Heavy metals were also detected in lichens in Soma (Gür and Yaprak 2011) and Yatağan (Ölgen and Gür 2011).

A correlation between  $^{210}\text{Pb}$  concentrations in tobacco leaves and rainfall was observed in Cankurt and Görgün (2020). The study was conducted in the Akhisar vicinity in

Manisa, which was 40 km away from Soma, where several CFPPs are in operation. Higher activity of radionuclides was reported in lichens and mosses in Çan and lichens in Soma (Sert et al. 2011; Belivermiş et al. 2016a). Authors studied in Çan stated that this activity mainly resulted from atmospheric deposition of CFPP emissions (Belivermiş et al. 2016a).

### Coal, bottom ash, and fly ash storage

Bottom ash, sludge of wastewater treatment, pre-treatment/washing wastewater sludges, and gypsum resulting from flue gas desulfurization units also cause land, surface water, and groundwater pollution. Spreading of the ash from open storage areas and reaching into the rivers implicate serious heavy metal pollution. Ash deposit sites have reached 300 ha in Muğla, which threatens the surrounding ecosystem (CAN Europe 2019). Coal storage on open land causes land and groundwater pollution. Open storage of coal also causes air-coal contact, causing pyrolysis of the coal, which leads to the formation of hazardous air pollutants. Ash storage areas constitute a major problem (TMMOB 2017). Leachates from coal storage areas are reported as another source of heavy metal pollution (Baba 2001). Enrichment of heavy metals in fly ash was reported in Çan, Çanakkale. As reported to have exceeded the threshold limits in the leachate of fly ash storage area even when the storage area was reported to be “a relatively new area” (Baba et al. 2008). As and Se in coal ashes were reported to have a higher leachability in several studies (Baba et al. 2008, 2010; Bilen and Yılmaz 2019). The leachability of heavy metals in fly ash, however, also depends on several factors such as the temperature of the water, pH, and presence of limestone (Baba et al. 2010).

Cr and Co release from Seyitömer CFPP exceeded the regulatory limits for drinking water and irrigation (Güleç et al. 2001). In Sarıçay, Pb, Cu, and Cr concentrations were significantly higher than EPA and Turkish standards (CAN Europe 2019). Several studies however reported contradicting results where authors reported negligible effects on surface water quality (Demirak et al. 2005), where one study discussed that other uncontrolled anthropogenic activities caused more pollution in surface waters than the CFPP (Güleç et al. 2001). Surface soil was found to be contaminated throughout Yatağan plain, and the highest concentrations were observed around the ash storage dam (Baba et al. 2003). Separation of unburnt carbon and removal of trace elements and other toxic elements are conducted in many plants, and therefore, the pollution is also transferred to the water that is used in the process (Baba et al. 2008). Ash storage also led to PCB pollution around Seyitömer CFPP, where samples from soils, sludge, ashes, and sediments were contaminated (Gedik and Imamoglu 2011).

Radioactive elements and heavy metals are also present in bottom ashes, resulting from the combustion of coal. Enrichment of toxic elements such as Mo, Cs, U, Zn, Pb, S, B, V, Zn, As, Cu, Co, and Hg were reported in CFPP ashes in Sivas (Karayığit et al. 2019b), Kütahya (Karayığit et al. 2019a), and Çanakkale (Baba et al. 2016), where caution with their disposal was advised. These radionuclides can spread from uncontrolled open storage areas, causing a great deal of land pollution (Avcı 2005). Baba (2002) reported that more radionuclides were present in the ashes than the feed coal in Yatağan. Enrichment of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  in fly ash samples from the temporary fly ash storage area of Yatağan CFPP was reported. Wetting of the ashes can contain the radioactive nuclides and prevent spreading to surrounding soils and water sources. However, this activity can cause radioactivity pollution in groundwaters (Baba 2001). Kursun et al. (2016) and Kursun and Terzi (2016) reported that uranium in uraninite ( $\text{UO}_2$ ) form and thorium in thorite ( $\text{Th}(\text{SiO}_4)$ ) form were found in the glass phase of fly ashes. These minerals are highly reactive and can be hazardous on high doses of exposure. The authors reported that these valuable minerals can be successfully recovered from the fly ash, with more than 80% efficiency.

Esen et al. (2021) conducted a hazard assessment study in 8 cities in Turkey throughout several geographical regions. The regions selected were home to the largest CFPPs in Turkey and selected in order to evaluate the ecological and health risks from radionuclides and heavy metals in soils, coals, and ashes of CFPPs. Average radioactivity concentrations were reported to be higher in coals and ashes than soils. Maximum doses of radionuclides in soil and freshwater organisms were observed in Çanakkale and Muğla, respectively. Reported doses overall were higher and lower than the screening values in freshwaters and soils, respectively. Excess lifetime cancer risk (ELCR) values were lower for soils but higher for coals and ashes. The highest ELCR values for coals and ashes were recorded in Sivas, and overall risk factors were higher for the Central Anatolia region. For heavy metals, the authors stated that health risks are predominant for people who live nearby coal fields and CFPPs. Akıncı et al. (2019) reported enrichment of As, Cd, Mo, Ca, and S in soils and bottom ashes. Mo, S, Cd, V, Cu, and Ca in the soils could be related to the CFPPs in the area, whereas Co, Mn, Ni, Pb, Fe, and Al were more likely to be related to geochemical properties of soil or use of agrochemicals and fertilizers in the area. The authors stated that translocation factors were for plant leaves than the seeds and fruits. Soil background concentrations, agrochemicals, particulate matter from coal storage, and fertilizers are evaluated to be the major contributors to plant bioconcentration, in decreasing order.

## Water use

Water is used in considerable amounts for cooling and cleaning purposes in CFPPs (Udemba 2021). Water is used as a heat exchanger, and therefore, its discharge temperatures are generally higher than the receiving environment which causes a change in water density, viscosity, and surface tension and lowers the rate of oxygen solubility. These factors, overall, negatively affect the organisms living in the receiving aquatic environment (Avcı 2005). Temperature change in water can also affect the dominance of species, causing invasive/alien species altering/reducing the diversity in the discharged environment (Doğa Derneği 2015).

The water has to be chemically treated prior to use in order to prevent the machinery in the plant. These processes result in the enrichment of chemicals in these waters, depending on the coagulant utilized in the process (Avcı 2005). These waters also absorb some pollutants and minerals while they circulate through cooling towers such as Hg (TTB 2014). The cooling water can also contain some ash and other particulate matter, which also creates pollution in the receiving water bodies (Avcı 2005). Some CFPPs, e.g., plants in Soma, Çan, and Karapınar, are located in highly water-stressed areas (Greenpeace 2016). In 2014, the majority of the CFPPs in Turkey used water cooling systems, where air cooling systems that do not require water (e.g., in Çan) represented only 10% of the installed capacity (Ekologos 2018). Although, both dry and wet cooling systems generally utilize wet scrubbers for capturing air pollutants, resulting in increased water demand (Greenpeace 2016). Kemerköy and Yeniköy CFPPs used 7.5- and 2.5-fold water in comparison to urban consumption of Yatağan and Milas, where they are located, respectively (CAN Europe 2019).

## Land use

CFPPs start to show their detrimental effects with mining of the coal in the first place, especially in open coal mining practices (Demirak et al. 2005). The trees are cut; the soil that has formed in million years, which is valuable for agriculture and forestry activities, is scraped. Rocks are crushed with explosives, and excavations are further continued in order to reach the coal that is 5–100 m deep. Those activities cause annihilation or massive destruction of trees, shrubs, herbaceous plants, fungi, lichens, algae, bacteria, viruses, reptiles, birds, mammals, and all of the other biological organisms that are a part of the forest ecosystem, thereby reducing the biological diversity and triggering erosion (CAN Europe 2019). In 2018, 5000 ha of land was used for open coal mining in Yatağan and Milas.

Moreover, issued permits for coal mining activities indicated that nearly 90,000 ha of land is ready to be used for



coal mining, of which 47.3–68% are forest areas (CAN Europe 2019). Because of coal mining activities in Muğla, it was estimated that nearly 39,000 ha of forest land will be destructed in the next 30 years (CAN Europe 2019). An area of 440,000 ha within some parts of Muğla and Aydın was investigated over satellite images from 1984 to 2018. 3800 ha of land was irreversibly destroyed, where 909 ha of the destruction resulted from lignite mining activities, where 1500 ha and 1390 ha of land was destroyed by quartz and marble quarries (Gül et al. 2019). National legislation requires the storage of organic soils after scraping. In 30–40 years of the average lifetime of a CFPP, the soil that is stacked mostly would lose its natural properties and will not be suitable for re-forestation purposes (CAN Europe 2019). The mining of coal also produces mining wastes that have to be dealt with (Demirak et al. 2005). Abandoned coal mining sites are also another source of pollution in the environment. Ovacik-Yapraklı abandoned coal site was reported to be contaminated with heavy metals, and higher heavy metal concentrations were observed in downstream of the surface water (Yenilmez et al. 2011). Arkoc et al. (2016) reported that there was no contamination of heavy metals in groundwaters around the mining field in Kırklareli, apart from a moderate level of contamination of As and Ni. However, they found out that there is contamination from human animal wastes in the groundwaters in the area.

Hunutlu CFPP, which is being constructed, is an important migration bottleneck. Even the air pollution induced by current industries causes a change in the migration behaviors of the birds, where the new CFPP will cause more exhaustion on birds that need to change their migration routes (Doğa Derneği 2015). Some coal mines operated are very close to natural preservation sites, and these sites are under pressure from coal mining activities (Gül et al. 2019). There are many inscribed archeological sites in 880 protection zones that are licensed as mining areas in Muğla (Büke and Köne 2011; CAN Europe 2019; Gül et al. 2019). The effect of abrasion/corrosion on historical heritage and eventually their destruction are cultural destructive effects of CFPPs. Several villages had to be displaced in Muğla (CAN Europe 2019), where several villages are affected by the pollution in Kahramanmaraş waiting to be displaced (Birgün 2019).

## GHG emissions and future energy mixture

Lignite and other types of CFPPs are one of the major contributors to the CO<sub>2</sub> emissions of Turkey. The CO<sub>2</sub> emissions were 79% of GHGs in 2019, followed by CH<sub>4</sub> (12%) and N<sub>2</sub>O (8%) (TÜİK 2020). Compared to the year 1990, the share of CO<sub>2</sub> in total GHG emissions has increased by 11%, where the emissions (in thousand tons) have increased by 174.5%, and the total increase of CO<sub>2</sub> emissions due to

energy production was 177.9% in 2018 (Ekologos 2018) and 130% increase of GHG emissions observed in 2019 (TÜİK 2020). Turkey only contributes to around 1% of GHG emissions in the world; however, the growth rate of GHG emissions is one of the fastest among OECD countries (Acar and Yeldan 2016) and the main contribution results from the energy sector (TÜİK 2020). According to Şahin et al. (2016), emissions from a CFPP average 1000 g CO<sub>2</sub> eq GHG (750–1500 g CO<sub>2</sub> eq/kWh electricity generated), whereas natural gas, wind, and solar average 500 g CO<sub>2</sub> eq/kWh, 15 g CO<sub>2</sub> eq/kWh, and around 45 g CO<sub>2</sub> eq/kWh electricity generated, respectively. Saint Akadiri et al. (2020) also supported that renewables such as solar photovoltaic panels, wind turbines, and hydropower generate less amount of CO<sub>2</sub> with 60–150 g CO<sub>2</sub>/kWh, 3–22 g CO<sub>2</sub>/kWh, and 4 g CO<sub>2</sub>/kWh electricity generated, respectively. Nuclear and coal power was responsible for 6 g CO<sub>2</sub>/kWh and 950 g CO<sub>2</sub>/kWh electricity generated.

National Climate Change Action Plan aims to limit the GHGs resulting from CFPPs via the use of clean coal technologies and measures to increase the efficiency of these plants until 2021. Hence, the average lives of these CFPPs will also be increased (Melikoglu 2017). Turkey plans to increase investments in CFPPs, contrary to the acceded climate change agreements (Acar et al. 2018). The Kyoto Protocol and the Paris Climate Agreement were signed by the government which requires a 21% decrease in GHG emissions (Telli et al. 2021). According to Şahin et al. (2016), if cumulative installed capacities of CFPPs in Turkey reaches 66.5 GW according to the announced programs, with 70% capacity utilized, these plants will emit 400 million tons of GHGs every year. This calculation was based on average emissions of 1000 g of CO<sub>2</sub> eq, where emissions resulting from lignite are expected to be higher. If one-third of this aim is actualized, half of this amount would be emitted to the atmosphere. In 2018, from 33 major CFPPs with 27,363 GW power generation capacity, Esmaili Aliabadi (2020) calculated a release of 134 million tons of CO<sub>2</sub> eq GHG emissions per year, which accounts for around 25% of total GHG emissions reported by the Turkish Statistical Institute for that year (TÜİK 2020). The GHG emissions of Turkey should be reduced to below 365 million tons CO<sub>2</sub> eq by 2030 and 226 million tons CO<sub>2</sub> eq by 2050 to be in line with the Paris agreement, which intends to hold the global average temperature increase below 2 °C and pursue efforts to limit the increase to 1.5 °C. However, current policies indicate that emissions are projected to be around 730–884 million tons CO<sub>2</sub> eq range (Climate Transparency 2020). The effect of subsidies on the coal sector is a major contributor to GHG emissions. Acar and Yeldan (2016) calculated a GDP decrease of 0.5% in 2030 was observed with the abolition of subsidies on coal but a substantial decrease in GHG emissions in their modeled scenarios for different income

regions. Karakaya et al. (2019) evaluated that decoupling of CO<sub>2</sub> emissions and economic growth in Turkey was only achieved in 2012–2013 and recently the performance was worsened.

Exemptions from environmental regulations also mitigate another problem where Turkey re-opened some of the CFPPs that were shut down at the beginning of 2020, which did not meet the emission threshold limits with temporary permission (Ember 2021). The studies reported and demonstrated significant pollution from CFPPs in Turkey except for several plants that utilize FGD and ESP systems, and only one plant exploits efficient coal incineration technologies (Vardar and Yumurtaci 2010; Büke and Köne 2011; Esmaili Aliabadi 2020). Higher emissions of SO<sub>2</sub> compared to other European countries, except several plants in Western Balkan countries, were observed as CFPPs with smaller installed capacities that emitted similar amounts of SO<sub>2</sub> than the most polluting Ukraine's larger CFPPs in Ember's study. The same conditions applied for PM 10 emissions and NO<sub>x</sub> emissions, where several Turkish plants were among the top 30 polluters with smaller installed capacities (Ember 2021). Economical resources for bearing the cost of subsidies, environmental issues, and health effects of CFPPs may deem the "cheap" coal a more expensive solution for meeting the energy demand (Acar and Yeldan 2016).

Although Turkey has a large potential to utilize RES, the cost of these technologies is also important for a renewable energy transition (Telli et al. 2021). As technology improves, the cost of renewables decreases and with subsidies diverted to RES, energy production with a larger portion of RES can be achieved by 2030. The use of coal as the main energy source may be advantageous in the short term; however, long-term risks to the environment and health need to be considered in development plans (Acar and Yeldan 2016; Esmaili Aliabadi 2020). In addition, phasing out from an economic model that supports coal technologies should be conducted as financial institutions also can no longer finance coal technologies due to changing conjuncture toward preventing climate change (Yeşil Ekonomi 2019), and investment and running costs are considerably high for CFPPs in large scale. Return of the investment for Hunutlu CFPP is expected to be in 26–30 years (WWF 2021). Financing of CFPPs and the coal sector as well as reserving more areas for coal mining would bring about a problem, where the energy sector becomes dependent on the coal and RES investments could not be at pace with coal investments. Therefore, this path would require additional investments in RES and perhaps other energy sources in the future. Therefore, shifting from coal also will not be possible due to high investments into these plants and that might cause a "path-dependence" (Acar and Yeldan 2016; Karakaya et al. 2019) for a long time which structured on maintaining coal and other polluting energy sources (Şahin et al. 2016).

Pathway for reaching a suitable energy mixture without damaging the environment and depleting the resources required for energy production (including renewables) should be planned for a long-term time period, considering the abovementioned issues with a proper balance to comply with GHG emission targets as well as environmental pollution prevention. Renewable energy investments can cause a larger technological dependency compared to the utilization of coal. However, mixed use of both technologies and conducting research and development studies on renewables can balance the technological dependency and environmental burden (Erat et al. 2021). Suitable financial and technical planning of investments and subsidies should be considered in energy policy in order to establish energy independence without severe subsequences (Atilgan and Azapagic 2017). Along with the increase of subsidies to RES, environmental taxation and supporting production with sustainable technologies should be implemented in order to reach a significant decrease in GHG emissions (Saint Akadiri et al. 2020; Telli et al. 2021). Inclusion of citizens by supporting rooftop solar panels with incentives and informing them about energy efficiency can also contribute to renewable energy production increase and reduced energy demand (Karasoy 2019; Çeçen et al. 2022).

The most utilized RES is the hydropower in Turkey, and it has a longer service lifetime along with reliability and cost-effectiveness (Telli et al. 2021). Turkey also has the largest hydropower potential in Europe (Bilgili et al. 2018). Although the environmental and social effects should be better evaluated (Aydin 2019). The geographical position of Turkey makes solar energy viable for Turkey with high energy generation potential (Telli et al. 2021) which is reported to be more than the current demand (Sirin and Sevindik 2021). During the 2014–2018 period, solar power investments grew rapidly but slowed down in mid-2019 due to changes in exchange rates and canceling of some supports (Çeçen et al. 2022). Implementing incentive policies for the longer term to support renewables is essential to sustain the energy generation from RES (Telli et al. 2021). Wind potential is also considerable both onshore and offshore, and onshore wind potential is utilized in various locations (Gönül et al. 2021; Telli et al. 2021). Bozcaada, Bandırma, Gökçeada, Inebolu, Karasu, and Samandağ were the coastlines that have a high potential of offshore wind farms which can be utilized, where several other coastlines had significant potentials but cannot be utilized due to restrictions (Emeksiz and Demirci 2019; Argin et al. 2019). Geothermal power is widely utilized and can be further exploited (Telli et al. 2021). However, Layman (2017) reported that geothermal plants installed in Turkey are not single-phase binary plants where the CO<sub>2</sub> and other gases remain in the solution. Due to the lack of the system, the evaporated gases are directly emitted to the atmosphere and emissions of 900–1640 g CO<sub>2</sub>/

kWh were reported by the author, except for two plants. The share of coal is lower than the world average, and therefore, with no additional coal installments, increasing renewables can benefit energy security and the environment (Karakaya et al. 2019). Coal and natural gas might be used in order to cope with the intermittency of RES (Esmaili Aliabadi 2020). Clean coal technologies, however, should be used in order to decrease the emissions from CFPPs (Melikoglu 2017). Clean coal technologies are at their early stages, but the time frame for emissions reduction is also tight. Therefore, clean coal technologies from developed countries with proven technologies should be purchased to decrease emissions while conducting research and development of national technologies (Melikoglu 2018). Carbon capture technologies can help acquire CO<sub>2</sub> which is a valuable product that can be sold, where there can be a demand to make it viable to capture and transport the carbon (such as in the regions close to the Middle East as investigated in Ađralı et al. 2018). Biomass plants can also be utilized to cope with intermittencies (Esmaili Aliabadi 2020) and several regions of Turkey, with widespread farming and animal husbandry practices providing significant opportunities for biogas production (Gorgulu 2019; Özer 2017) and wood-burning biomass alternatives (Toklu 2017).

Incekara (2019) conducted a modeling study in order to simulate the energy mixture by 2035. The author designed the model to minimize the cost of electricity generation and reduce GHG emissions, minimizing the imported energy, maximizing the efficiency in power generation, and minimizing the fossil use for energy generation. The model considered the aims of MENR and the responsibilities of Turkey according to bilateral agreements and excluded the aims for expansion of coal and natural gas power plants. In both high and low demand scenarios, for 2023, it was found that solar, wind, and hydropower plants were the top 3 sources for energy generation, followed by geothermal and natural gas following them, in decreasing order of percent distribution, respectively. The top 3 sources made up for 82% and 80% of energy generation for high demand scenario and low demand scenario, respectively. For 2035, in both high and low demand scenarios, the top 3 sources remain the same as 2023. In the high-demand scenario, they are followed by natural gas and biomass power plants, whereas in the lower-demand scenario, they are followed by biomass and geothermal power plants. The top 3 sources made up 62.3% and 69.7% of power generation in high demand and low demand scenarios, respectively. Natural gas plants with 11%, followed by geothermal power plants with 2.1% contribution that was estimated with the model, where biomass power plants with 10.6% and geothermal power plants were estimated to be used for energy generation. Considering the demand is going to increase, in 2035, 21% of electricity can be produced from nuclear and natural gas, where the rest

can be produced from renewables. The study shows that a significant decrease in GHG emissions can be achieved just by increasing RES while maintaining fossil fuel investments. Several other studies were also conducted to determine suitable energy policies and project emissions from energy generation in Turkey, considering CO<sub>2</sub> emissions and the relation of environmental parameters with income (Es and Hamzacebi 2021; Bakay and Ağbulut 2021; Karasoy 2019; Topcu et al. 2019). In order to reach net-zero emissions, along with carbon capture technologies, efficient energy conversion technologies along with energy storage investments to store the energy produced from RES should be utilized (Önay et al. 2021). Electricity transmission losses should also be addressed in policy to increase energy efficiency and lower GHG emissions (Önay et al. 2021).

## Conclusions

Turkey is an energy-dependent country, and the energy demand of the country stably increases, as with other developing countries. Turkey aims to increase the share of indigenous resources in energy production in order to decrease energy dependency. Coal is still a major source of energy worldwide and will continue to be preferred in Turkey according to National Energy and Natural Resources Strategic Plans to support energy independence, along with increased RES. Though the investments in RES increased, coal still holds a great share in electricity production. Renewables including hydropower are nearly equal to coal-based electricity generation, where RES excluding hydropower is nearly half of the coal-based energy generation. More CFPPs are planned to be built according to strategic plans, doubling the CFPP installed capacities until 2023. These actions were also further supported by incentives given to coal mining and the coal-based energy sector along with incentives to RES.

However, these plants cause a great deal of air, land, water, and groundwater pollution. With flue gases and fly ash emitted, bottom and fly ash storage, coal storage, water that is used for cooling and cleaning purposes, along with the land use for plants and mining sites, these plants considerably harm the environment. Emissions cause increased air pollution, where indigenous coals also bring about an elevated emission of SO<sub>x</sub>, apart from NO<sub>x</sub>, O<sub>3</sub>, CO<sub>2</sub>, CO, PM, and NMVOCs. SO<sub>x</sub> emissions of some 62% occurring from energy production demonstrate the effect of the elevated sulfur content of indigenous coals effect on emissions. Heavy metal and radionuclide content of the coals utilized is also widely studied, and enrichment of heavy metals is also observed in the vicinities of CFPPs. Ash storage and coal storage were also extensively studied with demonstrated effects of elevated heavy metals

and PCBs in water sources and groundwaters. Radionuclides were also found to be enriched in the storage areas. The effect of these emissions and the storage activities on humans, animals, vegetation, and biota was also studied and reported throughout the whole of Turkey.

Legislations that subsidize the coal sector and planned large-scale CFPPs in 2030 bring about increased coal mining and land use effects, further threatening the environment as well as cultural sites. They are also supported by exemptions from taxes and sometimes environmental legislation. But, moreover, they are causing elevated GHG emissions, and with new plants constructed, yet to cause a substantial increase of GHG emissions and jeopardize the targets for 1.5 °C world and 2 °C warmer world. Turkey is located in one of the most sensitive areas to this temperature change and is going to be adversely affected from resulting weather extremities. Although the Kyoto Protocol and the Paris Climate Agreement were ratified by the government and these ratifications call for an urgent reduction of CO<sub>2</sub> emissions, the current strategy will further increase the GHG emissions. Therefore, planning of energy mixture should be carefully conducted in order to utilize more RES in the energy mixture.

Turkey has a high potential for RES, particularly hydro, solar, and wind are the most potent sources of RES. Phasing out of coal should be accelerated as financing coal will be expensive in the near future, nonetheless its effect on the environment. At least, coal investments should be canceled, and they can be used as measures for intermitencies. Clean coal technologies, carbon capture and storage (CCS) units, and FGD and ESP systems should at least be utilized in existing plants as much as possible in order to reduce the pollution from CFPPs, before phasing out of coal. A faster pace of increase in RES should be prioritized in order to protect the environment, people, and cultural heritage of Turkey. With increasing of RES, canceling the new CFPPs, reducing the transmission losses, utilizing clean coal and carbon capture technologies to reduce the impacts of CFPPs, and adopting measures to reduce the energy consumption, the Turkish energy sector can both reduce its energy dependency and can increase the environmental quality. Subsequently, phasing out of coal can be initiated as these RES increased with increased incentives on these resources and keeping up with the de-carbonization. Otherwise, Turkey, in a geographical location that is highly sensitive to adverse climate change effects and dependent on fuel imports, cannot reach future years with a sustainable energy sector and increased environmental quality.

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## Declarations

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